# *The Flame Arising from the Nitrogen-burning Arc.*

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(Received July 12, 1911.)

## § 1. *Introduction.*

Sir William Crookes was the first to draw attention to the flame arising from the high-tension alternating arc in air, and to point out that it was connected with the oxidation of nitrogen.* It was extensively used by Lord Rayleigh in connection with the isolation of argon, when I first had the opportunity of becoming acquainted with it. Of late years it has come into prominence in connection with the commercial manufacture of nitrogen compounds from the air, and is now within the purview of the electrical engineer.

Some investigations upon which I have recently been engaged have thrown considerable light on the processes occurring in this flame. The conclusions reached are not in agreement with some which have been expressed by other workers.†

## § 2. *The Arc in Pure Gases and in Air.*

If a Ruhmkorff coil or other form of high-tension transformer is supplied with alternating current in the primary circuit, an arc can be struck between the secondary terminals, which, for experimental purposes, are best made of platinum. A similar arc is obtained, using a continuous current interrupted by a Wehnelt or mercury turbine break. It is convenient to begin by considering the appearance of this arc in pure gases.

In hydrogen the discharge is observed to stretch straight across between the electrodes, without appreciably rising into an arch.

In pure nitrogen the phenomena are similar, except that the discharge tends to rise into an arch, particularly if the terminals are widely separated.

In pure oxygen an arch is also formed. In this gas the discharge has a bluish-white colour, and is much more diffuse than in the former ones. To a casual examination it may have somewhat the appearance of a flame; but the difference from the other pure gases is only one of degree. Close examination shows that there is nothing there but the true current-carrying arc itself.‡

* 'Chem. News,' 1892, vol. 65, p. 301.

† See, for instance, F. Howles, 'J. Soc. Chem. Industry,' 1907, vol. 26, p. 290.

‡ Compare Rayleigh and Ramsay, 'Phil. Trans.,' A, vol. 186, p. 219 (second paragraph).

With air, an entirely new phenomenon makes its appearance. The arc is there as before, stretching from one terminal to the other, with a slight rise in the middle. But around, and more particularly above, it is an envelope of yellowish-green flame, which may rise to a considerable height above the arc, and terminates above in quite a sharp point, like a candle flame.

At atmospheric pressure the luminosity of the arc proper is so slight as to make it somewhat difficult to distinguish from the surrounding flame. The flame, however, gives no violet rays, while the arc is rich in these rays. Accordingly, the arc may be seen alone by examination through a deep violet glass, and then appears of about the same size and form as in pure nitrogen.

Fig. 1 shows a photograph of the air arc isolated in this way by a violet glass. Fig. 2 shows a photograph taken with an hour's exposure through a

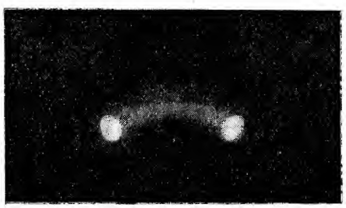

Fig. 1.

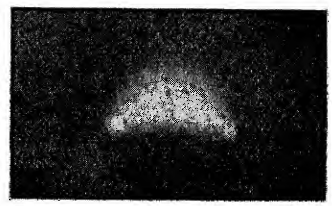

Fig. 2.

combination of green and yellow glass, which excludes the violet rays, but transmits the yellow and green ones in which the flame is richest. In this way a picture of the flame appears, without blurring by the intensely actinic glare of the arc proper. The photograph hardly brings out the pointed tip of the flame as distinctly as might be wished. This is probably due to the slight flickerings of the flame, inevitable during a long exposure.

The distinction between the arc and the flame may be made even clearer by another method, that of moderately reducing the air pressure. A rose-coloured arc is then clearly seen, quite distinct in colour from the surmounting yellow-green flame, and separated from it by a slight dark interval. Under these conditions it is quite obvious that the former alone carries the current (fig. 3). The flame, which does not appear in pure gases, is due to secondary causes which will appear in the sequel.

If we continue to reduce the pressure, and at the same time draw the electrodes further apart, the yellow-green flame expands. The phenomena become more conspicuous if, concomitantly with the reduction of pressure, the percentage of oxygen present is increased. Finally, the yellow flame fills the whole vessel, which none the less remains cool enough to allow the hand

to be placed upon it. The flame remains visible for a moment after the arc has been switched off (fig. 4).

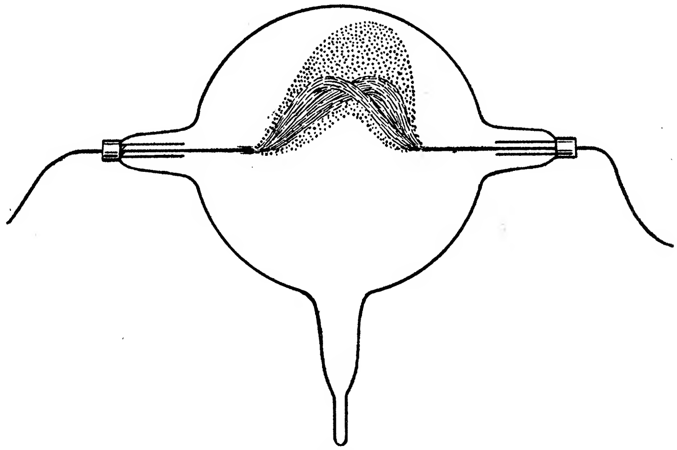

Fig. 3.

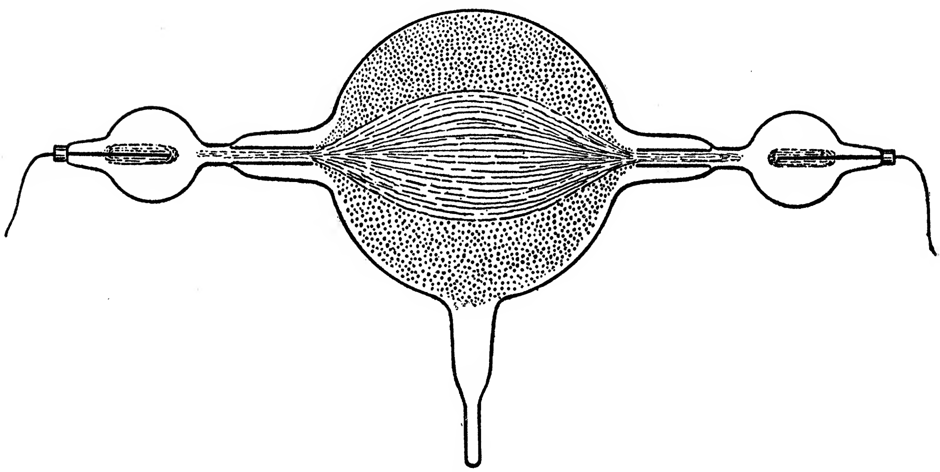

Fig. 4.

At this stage it is evident that the nitrogen flame is in no way distinct from the well-known "after-glow" sometimes observed in Geissler tubes filled with air*—a luminosity which persists after the discharge is over. This phenomenon I traced to its origin in a paper read before the Physical Society.† It will be convenient to briefly mention some of the experiments there described in detail.

* Not to be confounded with the glow due to active nitrogen, see 'Roy. Soc. Proc.,' A, 1911, vol. 85, p. 219.

† 'Phys. Soc. Proc.,' December 15, 1910, vol. 23.

A current of rarefied air was drawn through a vacuum discharge tube by means of a power air pump. It remained luminous with the characteristic greenish-yellow light leaving the discharge, but this luminosity was destroyed by passing through silver wire gauze. Now, silver destroys ozone. It appears, then, that ozone is bound up with formation of the glow.

The greenish-yellow glow is not, however, observed in the absence of nitrogen. It was found that air deprived of the glow by silver gauze would glow again when more ozone was led into it. The air therefore contained some second ingredient necessary to the glow. This ingredient was concluded to be nitric oxide, formed by the discharge; and it was shown that the glow could be reproduced by leading ozone into nitric oxide, chemically prepared. It has been observed since that nitrogen peroxide gives the same result. The glow then is due to the further oxidation by ozone of oxides of nitrogen already formed in the arc. The arc supplies both ozone and nitrogen oxides, which combine, giving the greenish-yellow flame.

It is known that ozone will oxidise nitrogen peroxide to the pentoxide. When nitric oxide is led in, it is oxidised in two stages, first to peroxide, then to pentoxide. There is no doubt that the greenish-yellow flame is developed in the second stage; for I find that it is produced when ready-made nitrogen peroxide is fed into a stream of ozone. But if, as appears likely, the yellow-green luminosity is due to the nitrogen peroxide molecule, it may be evolved in the formation of that molecule from nitric oxide as well as in its subsequent further oxidation.

To sum up, the greenish-yellow flame from the high-tension alternating arc in air is shown to be in complete continuity with the "after-glow" phenomenon in vacuum tubes containing air. The latter can, by suitable experimental analysis, be proved to be due to the further oxidation of oxides of nitrogen by ozone. Accordingly it is concluded that the flame arising from the arc is due to the same cause. The arc produces ozone and oxides of nitrogen. These substances, independently produced, unite chemically in the region above and around it. The greenish-yellow flame is developed in the process.*

* It is right to mention that Muthman and Hofer, 'Ber.,' 1903, vol. 36, p. 440, express the opinion, for which, however, they do not offer any experimental evidence, that oxidation of NO proceeds in the flame. They do not mention ozone in this connection.

FIG. 1.

FIG. 2.